PERFORMANCE COMPARISON BETWEEN PREFABRICATED VERTICAL DRAINS (PVD) AND ELECTRICAL VERTICAL DRAINS (EVD) ON MARINE SOIL

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CERTIFICATION OF APPROVAL

Performance Comparison between Prefabricated Vertical Drains (PVD) and Electrical Vertical Drains (EVD) on Marine Soil

by

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Approved:

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohammad Nabil Fikri Bin Razali

ABSTRACT

This report basically discusses the interim research done and basic understanding of the chosen topic, which is **Performance Comparison between Prefabricated Vertical Drains (PVD) and Electrical Vertical Drains (EVD) on Marine Soil.** The research determined the performance comparison between PVD and EVD on marine soil in term of undrained shear strength, water content, current variation, pH and settlement. A series of laboratory tests were conducted under similar surcharge of 2.5kPa with voltage variation of 5V, 10V and 15V. The soil shear strength in laboratory test increased between 0.416kPa and 2.49kPa to between 3.33kPa and 17.64kPa on average of 7 days treatment of PVD and EVD respectively. It is observed that the significant shear strength increased is attributed to the reduction of water content which results from electro osmotic consolidation, applied load and electrochemical reactions.

Keyword: Marine Soil, Electro-osmotic, Prefabricated Vertical Drains (PVD) and Electrical Vertical Drains

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CHAPTER 1: INTRODUCTION

1.1 Background of Research

Clay is a naturally occurring material, composed primarily of fine-grained minerals, which show plasticity through a variable range of water content. Clays are distinguished from other fine-grained soils by various differences in composition. Silts, which are fine-grained soils which do not include clay minerals, tend to have larger particle sizes than clays, but there is some overlap in both particle size and other physical properties, and there are many naturally occurring deposits which include both silts and clays.

Marine clay is a type of clay found in coastal regions around the world. Marine clay consists of bluish gray, red and yellow, clayey and silty soils that were deposited by rivers flowing into the ocean millions of years ago. Marine clays can be found in discontinuous layers often scattered with thin layers of sand. When clay is deposited in the ocean, the excess ions allow a loose, open structure that is open to water infiltration. Once stranded and dried by ancient, changing ocean levels, it becomes a geotechnical engineering challenge.

Deposits of soft clay soil pose construction problems related to settlement and stability. Soil stabilization is very crucial to the stability of the structures lying on top of and underneath it. Unstable soil, whether by settlement or expansion, has cause severe damages to structures in the past. This is applies also for structures on under the marine conditions. Poor ground conditions have also proved to render construction costs rising. Thus, it is economically feasible to improve the engineering properties of the ground first before commencing the structure construction.

1.2 Problem Statement

A common soil improvement technique in such deposits is the application of prefabricated vertical drains (PVD) with or without surcharge to eliminate a large proportion of primary consolidation settlement and secondary settlement. Recently, the electrical vertical drains (EVD) were invented to combine drainage and electrokinetic functions. Electro kinetic stabilization is a soil improvement technique that is commonly used for fine-grained soils such as silts and clays. This paper describes a study of performance comparison in soft marine clay using PVD and EVD with copper electrodes. The comparative influence of these two different stabilizations in terms of undrained shear strength and water content is the main objective of this study.

1.3 Objective of Research

Two main objectives are as stated below:

1) To study the effect of electrical vertical drains (EVD) on marine soil's strength properties

2) Investigate the performance comparison between electrical vertical drains (EVD) and prefabricated vertical drains (PVD) on marine clay

1.4 Scope of Research

The increasing complexity of construction in urban environments and coastal region has led to a need for more comprehensive geotechnical analysis techniques. This project is related to geotechnical engineering part specifically involving soil investigation.

This project also can be in the form of laboratory experiments, data analysis and fabrication of laboratory apparatus. The properties of soil such as unit weight, porosity, permeability, consolidation, specific gravity, shear strength, particle size distribution and atterberg limits are used in the analysis of stabilization of clay soils as well as marine clay.

1.5 Research Activities

During the research, several factors should be taken into consideration such as the economical aspects and the engineering properties of the PVD/EVD and also soil samples. This is to ensure that the PVD/EVD is suitable to produce an effective result and be able to improve the engineering properties of the soil. The research activities are divided into several stages:

1.5.1 Selection of Location

As a base of this research, several journals, books and related articles are referred to in gaining deeper perceptive and understanding. Case study had been made to specify the suitable location for acquiring the soil sample. Marine Geologist at Technical Services Division, Minerals and Geosciences Department Malaysia, Ipoh, had suggested the location to be selected in Kg. Acheh Lumut, Perak.

1.5.2 Collecting Samples

Marine clay soil sample had been collected at Kg Acheh Lumut, Perak. Both disturbed and undisturbed samples were collected. The disturbed sample was taken half a meter deep from the top soil. The undisturbed sample was taken using the hand auger. This sampler typically consists of a short cylinder with a cutting edge attached to a rod and handle. The sampler is advanced by a combination of rotation and downward force.

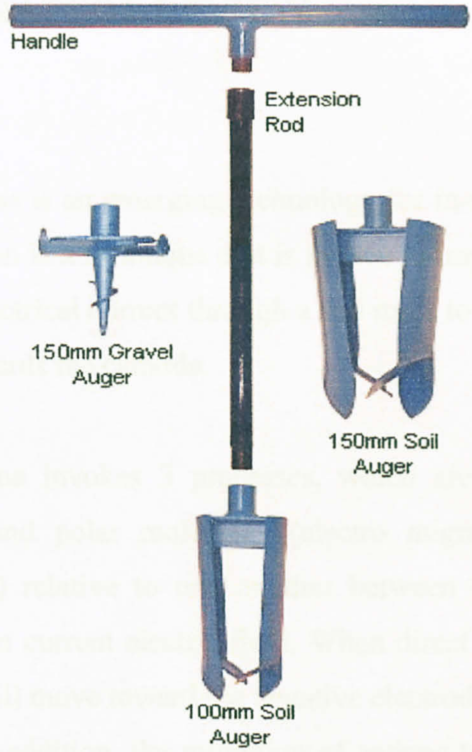

Figure 1.5.2.1: Diagram of Hand Auger

These augers are suitable for hand-boring in cohesive soils or sands and gravels, above the water table to a depth of 5 or 6 meters. Soil Auger Heads are constructed of heavy duty steel plates forming an open tube partly interlocking at the cutting end. Two diameters are available - 100 mm or 150 mm. The auger heads is connected to Extension Rods constructed of steel tubing 1 meter long. A Handle with T-piece is attached to the uppermost extension rod.

CHAPTER 2: LITERATURE REVIEW

2.1 Electrokinetic

The Electro kinetic process is an emerging technology for in-situ soil stabilization. The Electro kinetic stabilization is a technique that is known to improve the volume stability of the soil by applying electrical current through a soil mass to induce movement of pore water from the anode towards the cathode.

Electro kinetic phenomena invokes 3 processes, which are the movement of water (electro-osmosis), ions and polar molecules (electro migration) and charged solid particles (electrophoresis) relative to one another between two electrodes under the action of an applied direct current electric field. When direct current is passed through soil, the aqueous phase will move toward the negative electrode (cathode) by the electro-osmosis phenomenon. In addition, the migration of cations to cathode while anions to anode. These processes, referred to as Electro kinetics, can be used to remediate contaminated soil without excavation.

One of the techniques is electro kinetic stabilization. The technique consists of applying direct current (DC) electric fields through a wet soil mass via a pair of electrodes to promote the migration of stabilizing agents into the soils. This technique had been proved effective in improving the soil strength of soft soil such clay as published by some researcher.

However, electro kinetic stabilization has not yet become widely accepted in real practice as it provides significant improvements only within a limited area. The results of several experiments revealed that non-uniform strength improvement is obtained after treatment. The quality of improvement decreases from the cathode to the anode.

A depolarization of electrokinetic stabilization is introduced by Asavadorndeja (2004) in his research where hydroxide ions are applied at the anode which depolarized hydrogen ions generated from electrolysis. This technique prevents the formation and thus migration of the hydrogen ions (which hinder the stabilizing processes) into the soils. Therefore, uniform strength improvement of the soil is obtained.

2.2 Electro osmosis

Electro-osmosis invoke from electro kinetic is the process to decrease water content in soil and increase the shear strength of soil since the strength of soil is expressed by effective strength (σ') and pore water pressure (u) as shown below

$$\sigma' = \sigma - u \qquad (1)$$

Whereas electro kinetic stabilization is a technique of applying an electrical current through a soil to promote the migration of chemicals to react with the soil sample in order to improve the characteristic of soil. From past researches, it has been found that electro-osmosis is able to extract radionuclide, heavy metals, certain organic compound or mixed organic species and organic waste (Acar *et al,* 1995).

Combination between electrical, chemical and hydraulic gradients is responsible for different types of electro kinetic phenomena in soils (Mitchell, 1976). Electro-osmosis is one of these phenomena, the pore fluid moves due to application of constant low DC current by electrode inserted in a soil mass. In the five decades since its first application (Casagrade 1947), electro-osmosis has been investigated and used for different applications, such as improve stability of excavation (Chappell and Burton 1975), stabilization of fine-grained soils (Mitchell and Wan, 1977)

The effect of electric current on water inside the soil mass are as the same as electrolysis concept whereby water molecules are being oxidized and reduced at anode and cathode respectively. These two processes create some difference in pH level across the soil mass. These pH variations in turn change the surface change on clay minerals, and thus cation exchange capacity and the solubility of elements within the soil structure (Acar and Alshawabkeh, 1993). Equation (2) and (3) describe the half reactions of water electrolysis at anodic and cathodic surfaces produces oxygen and hydrogen respectively.

$$2H_2O - 4e^- \rightarrow O_2 + 4H^+ \quad \text{(Anode)} \tag{2}$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad \text{(Cathode)} \tag{3}$$

The applications of direct current to the soil-water system induce physicochemical reactions to occurred. If the electric current conducted in ground, by pH variation due to electrolysis, fluid transport mechanism and surface characteristic changed and also due to interactions such as ion property, conductivity and chemistry in electro kinetic remediation system reactions change. The reaction that occurs involving the electrodes and pore water mostly depends on the characteristic of the pore water and substance properties of the electrodes. From this project, both electrodes being used are copper. From electrolysis basic theory, it is been known that at anode is the electrode where the process of donation of electrons takes place while cathode is the electrode where the process of acceptance of electrons takes place. Since copper is an active electrodes, thus at anode,

$$Cu \rightarrow Cu^{2+} + 2e^- \quad \text{(Anode)} \tag{4}$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad \text{(Cathode)} \tag{5}$$

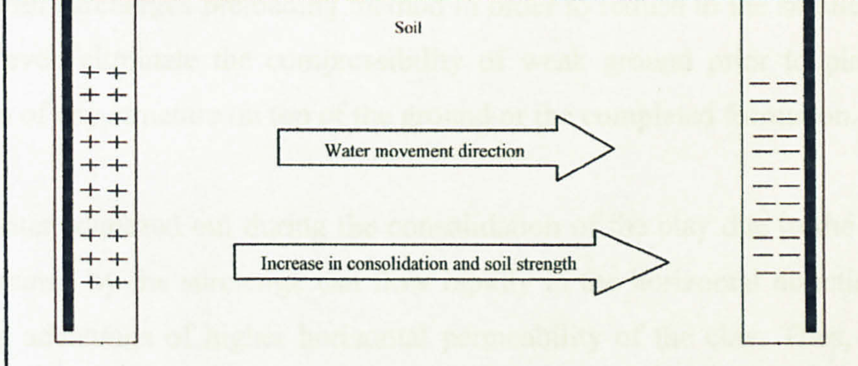

Figure 2.2.1: Electro-osmosis Phenomena in Soil

2.3 Prefabricated Vertical Drains

Prefabricated Vertical Drains (PVD) with surcharge preloading is one of the most widely used techniques to accelerate the process of consolidation of the clay layer. PVD also installed in order to gain rapid strength increase to improve the stability of structures on weak clay soil. The installation of PVD can be achieved in a various ways depending upon the type of drain to be installed and the nature of the ground that can cause significant disturbance to the surrounding soil. The permeability of the clay layer is greatly reduced due to the reorientation of the soil particles which is commonly known as 'smear'.

Prefabricated vertical drains is artificially-created drainage paths consisting of synthetic filter jacket surrounding plastic cores which are inserted into the soft clay subsoil. Basically, there are three advantages of PVD which is:

1. Increased rate of gain of shear strength of clay
2. Increased rate of consolidation
3. Stability to embankments and tankages.

The rapidity and economy of the drain installation coupled with cheap readily available vertical drain material have made this method in combination with surcharging a much more useful and cost effective ground improvement technique. PVD is normally combined with surcharges preloading method in order to reduce to the smallest possible amount or even eliminate the compressibility of weak ground prior to placement or construction of any structure on top of the ground or the completed formation.

The pore water squeezed out during the consolidation of the clay due to the hydraulics gradients created by the surcharge can flow rapidly in the horizontal direction towards PVD taking advantage of higher horizontal permeability of the clay. Thus, these pore water can flow freely along the PVD vertically toward the permeable layers and will result in shorten length of drainage path and eventually accelerates the consolidation process and allow clay to gain rapid strength increase.

The soil is consolidated when the soil porewater drained out from the soil. Prefabricated Vertical Drains (PVD) is used in combination with the preloading technique to shorten the drainage path in the soil, hence reduce the time of primary consolidation (A.Rittirong, R.S. Douglas, J. Q. Shang and E.C. Lee 2008).

2.4 Electrical Vertical Drains

The applications of polymer vertical drains combine with electricity can be used to accelerate consolidation of clay. From the previous research, the combination of drainage and electro kinetic functions has demonstrated geotechnical engineering applications such as the stabilization of reinforced soil wall, the consolidation of mine tailing deposits and the separation of solids in sewage sludge (Glendinning *et al*. 2005; Tyagi 2006; Fourie *et al*. 2007; Glenndinning *et al* 2007).

The electrical vertical drains (EVD) product works by taking the advantages of PVD to provide vertical drainage as well as conductivity of the core to facilitate electric current flow into the soil enabling electro osmotic (EO) process. The electrodes used in conventional electro kinetic treatment are made of steel, aluminium and copper. These electrodes corrode rapidly during treatment which diminishes treatment efficiency. Hence with polymer material from PVD combine with electrodes will reduce the corrosion of electrodes.

The electro-osmotic consolidation technique combined with vertical drains can accelerate soil consolidation develop electrical vertical drains (EVD) based on PVD and used them as electrodes and vertical drains in a land reclamation project. (Wan and Mitchell 1976; Shang 1998; Bergado et al. 2000; Chew et al. 2004)

CHAPTER 3: METHODOLOGY/PROJECT WORK

3.1 Introduction

For this project, methodology is divided into two stages whereby it is conducted in two stages. In the first stage, it involved the basic testing on Marine Clay samples and then, the actual test will be carried out next. As for the later stage, the Prefabricated Vertical Drains (PVD) and Electrical Vertical Drains (EVD) stabilization experiment is conducted as well as the basic testing earlier to determine the change in properties of Marine Clay. Literature review was done to understand the aspect of PVD and EVD treatment and process on soils.

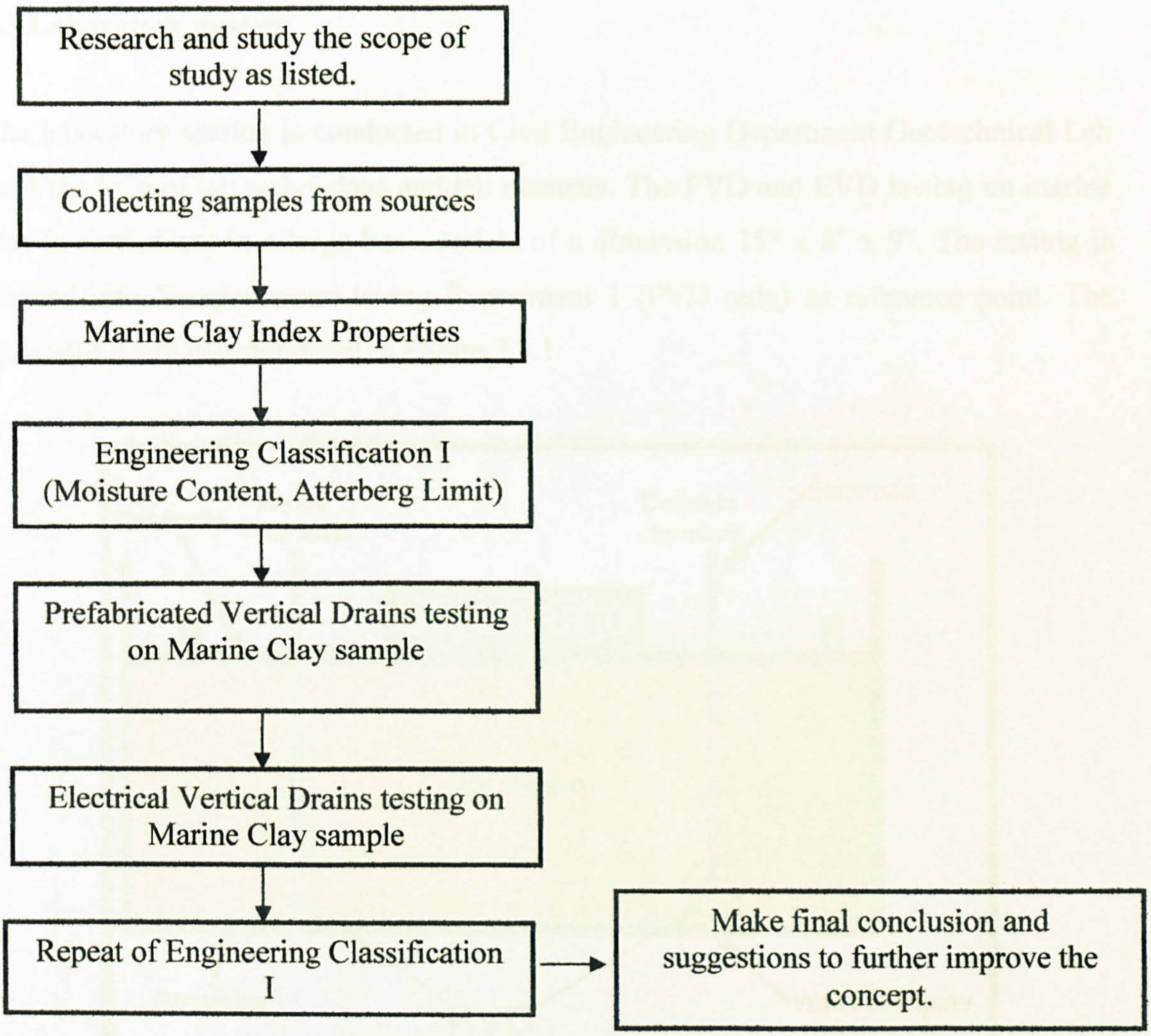

Figure 3.1.1: Flow chart of activities

3.2 Research Methodology

3.2.1 Literature Review

Additional research was carried out to find more related articles. Literature Review was the analytical and objective review of written materials on the chosen topic and area. It provided the background information on the research question and to identify what others have said and/or discovered about the question. It contained all relevant theories, hypotheses, facts and data which were relevant to the objective and the findings of the project.

3.3 Laboratory Session

The laboratory session is conducted in Civil Engineering Department Geotechnical Lab with the help of lab technicians and lab manuals. The PVD and EVD testing on marine clay is carried out in a large box consists of a dimension 15" x 8" x 9". The testing is divided into 5 experiments taking Experiment 1 (PVD only) as reference point. The apparatus setup is generalized in Figure 3.3.1

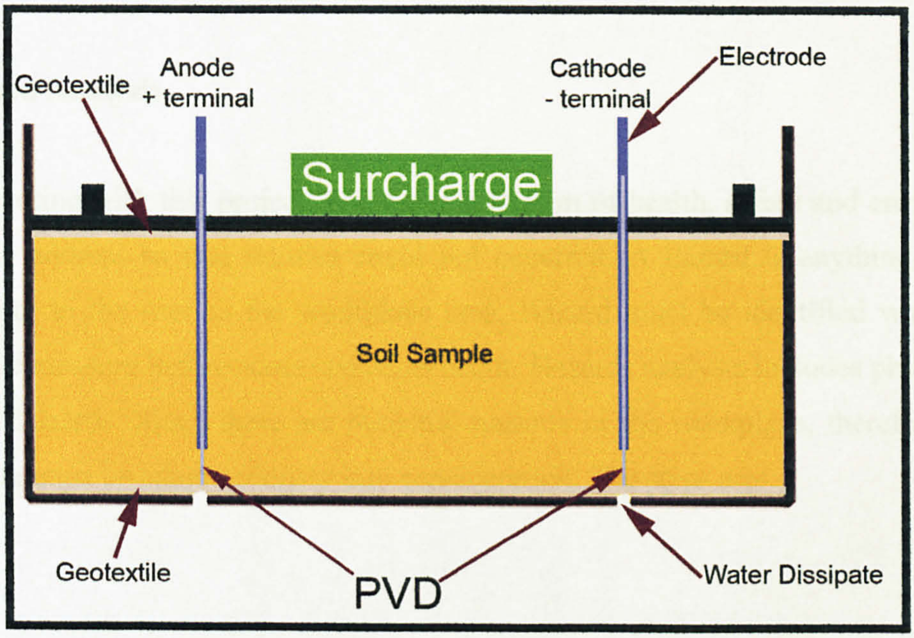

Figure 3.3.1: Side View of Model Tank

Table 3.3.1 below shows the value of voltage and electrodes used for the experiments

Experiment	Electrode	Voltage	Surcharge
1 - PVD	-	-	2.5kPa
2 - EVD	Copper Wire	20V	2.5kPa
3 - EVD	Stainless Steel	5V	2.5kPa
4 - EVD	Stainless Steel	10V	2.5kPa
5 - EVD	Stainless Steel	15V	2.5kPa

Table 3.3.1: Total of 5 Experiments Conducted

The experiment is conducted on marine clay in which to compare the performance comparison between PVD and EVD and to determine whether EVD testing can affect the soil strength and moisture content of marine clay. There are 4 important parameters that need to be observed in order to compare performance comparison between PVD and EVD. Those 4 parameters are:

- Moisture Content
- Shear Strength
- pH
- Settlement

3.4 Hazard Analysis

While working with this project, few matters in term of health, safety and environment should be address so that injuries could not occurred. A hazard is anything that can cause harm to the user in the workplace area. Hazard must be identified which is as preventive measure before some accidents occur. Hazards analysis includes physical and chemical hazards. Since there are potential hazards in the workplace, therefore safety precaution must be taken seriously into consideration. The steps are:

1. Always wear goggle when dealing with soils since silt and clay can enter the eyes and cause ache to eyes. Make sure that if the accidents happen, never rubbed off eyes and go to see the doctor as soon as possible.
2. Do not wear any contact lens when dealing with oven. The contact lens may melt due to the heat coming from the oven.
3. Always wear gloves when dealing with oven where hot temperature inside it can be hazardous to both arms.
4. The waste soil coming from the experiments should be put into a specific dust bin so that it can be dumped at a correct location and it may not cause any harm to the people surround the laboratory.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Test Setup

A total of 2 model tanks with the same dimension were designed and assembled as experiment of PVD and EVD for performance comparison research is being carried. These two model tanks were made of perspex which is a non conductive material, transparent, waterproof and also to sustain the load from the soil/surcharge without cracks. This soil stabilization on perspex tanks will be easily observes because of its transparency properties. The need for having two model tanks with the same dimension was to allow 2 tests run simultaneously which is PVD and EVD.

Another material used for the testing is geotextile. A layer of geotextile is placed at the top and bottom of the box (Figure 3.3.1) in order to avoid any marine clay particle to discharge out from the box together with water.

The experiment of PVD and EVD on marine clay is running for a period of 7 days. After that, 4 important parameters which is moisture content, shear strength, settlement and pH is determined at specific placed in the box using auger sampling tube. A total of five different spot labeled with 1,2,3,4, and 5 as shown at schematic Figure 4.1.1 below is taken to determine the performance comparison between PVD and EVD testing on marine clay.

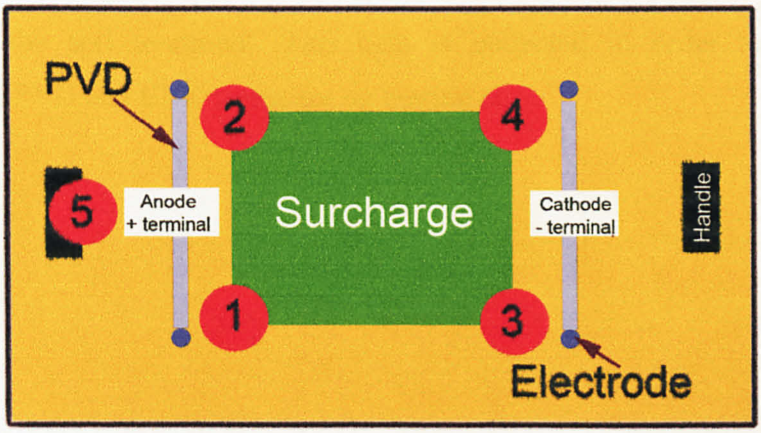

Figure 4.1.1: Plan View of Model Tank

4.2 Soil Sample

The soil sample used for this study was taken at Kg. Acheh Lumut, Perak. After taking the sample at Kg. Acheh, the marine clay is fully dried in the oven with temperature of 105°C for the PVD testing. After that, the marine clay sample is sieved passing 2.00mm to make sure it is at powder form. To obtain better homogeneity, the soil was mixed with distilled water to reach slurry at the same amount at every test that will be conducted as stated below:

Weight of soil=10kg
Weight of water=5.5kg

The marine clay samples were mixed together with distilled water using mixer for 15 minutes. After that, the soil sample is wrapped up with plastic and left out for 24 hours to allow homogenous state to occur. The marine clay sample is mixed with distilled water because distilled water is free of ion, microorganism and other content that might affect the testing and observation.

4.3 Results

The result of Prefabricated Vertical Drains (PVD) and Electrical Vertical Drains (EVD) testing is carried out by taking at least 2 samples (Anode and Cathode) from 5 spotted areas as shown in Figure 4.1.1 to determine their moisture content, pH and shear strength after the soil treatment. This data is collected in order to compare the performance of PVD and EVD treatment on marine clay.

4.3.1 Moisture Content

The moisture content results are shown in Table 4.3.1.1 below for all experiments conducted. For each experiment, 5 different samples at 5 different spots (Figure 4.1.1) is taken out using sampling tube and divided into three portions of samples to be taken as moisture content. The most bottom part of sampling tube will be labeled as no. 1, 2 and 3 as shown at Figure 4.3.1.1 and an average value of moisture content is calculated for each sample area.

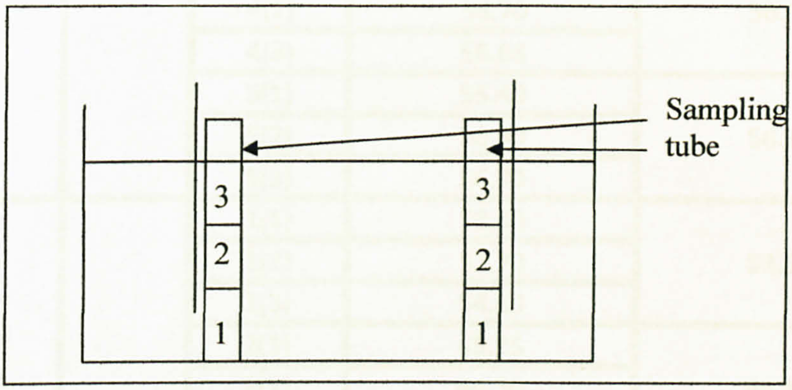

Figure 4.3.1.1: Side View of Model Tank (Sampling Tube)

EXP	Treatment	Voltage	Container	Moisture content (%)	Moisture content (%)
1	PVD with 2.5kPa Load	0V	1(1)	52.70	53.87
			1(2)	54.10	
			1(3)	54.80	
			2(1)	52.20	53.17
			2(2)	53.00	
			2(3)	54.30	
			3(1)	53.04	54.25
			3(2)	54.40	
			3(3)	55.30	
			4(1)	52.00	53.70
			4(2)	54.50	
			4(3)	54.60	
			5(1)	52.30	53.27
			5(2)	53.50	
			5(3)	54.00	

			1(1)	55.00	
			1(2)	55.20	55.30
			1(3)	55.70	
			2(1)	54.96	
			2(2)	55.83	55.50
			2(3)	55.70	
			3(1)	54.10	
2	EVD (Copper Wire) with 2.5kPa Load	20V	3(2)	56.50	55.75
			3(3)	56.65	
			4(1)	54.72	
			4(2)	56.70	56.03
			4(3)	56.68	
			5(1)	55.40	
			5(2)	56.30	56.13
			5(3)	56.70	
			1(1)	53.30	
			1(2)	52.70	53.60
			1(3)	54.80	
			2(1)	45.25	
			2(2)	44.30	45.18
			2(3)	46.00	
			3(1)	68.26	
3	EVD (Stainless Steel) with 2.5kPa Load	5V	3(2)	67.00	67.00
			3(3)	65.74	
			4(1)	66.35	
			4(2)	67.15	67.21
			4(3)	68.13	
			5(1)	47.58	
			5(2)	49.15	48.50
			5(3)	48.76	
			1(1)	51.25	
			1(2)	46.65	49.40
			1(3)	50.30	
			2(1)	52.40	
			2(2)	52.50	52.68
4	EVD (Stainless Steel) with 2.5kPa Load	10V	2(3)	53.14	
			3(1)	59.50	
			3(2)	61.20	62.33
			3(3)	66.30	
			4(1)	69.50	72.33
			4(2)	74.80	

			4(3)	72.70	
			5(1)	51.70	51.22
			5(2)	50.25	
			5(3)	51.70	
5	EVD (Stainless Steel) with 2.5kPa Load	15V	1(1)	44.31	45.01
			1(2)	43.86	
			1(3)	46.85	
			2(1)	45.26	46.42
			2(2)	46.36	
			2(3)	47.65	
			3(1)	70.34	75.96
			3(2)	76.59	
			3(3)	80.94	
			4(1)	73.43	76.21
			4(2)	75.93	
			4(3)	79.26	
			5(1)	47.26	46.53
			5(2)	46.15	
			5(3)	46.18	

Table 4.3.1.1: Moisture Content Result

The formula used to calculate moisture content is:

$$\text{Moisture content, } w = \frac{(m_2 - m_3)}{(m_3 - m_1)} \times 100$$

Where:

(m_1) = Mass of container
(m_2) = Mass of wet soil + container
(m_3) = Mass of dry soil + container
$(m_2 - m_3)$ = Mass of moisture
$(m_3 - m_1)$ = Mass of dry soil

4.3.2 Vane Shear Strength

The value of torque applied to shear the soil is calculated by using the formula shown below:

$$\boxed{\text{Torque, } M \text{ (N.mm)} = K\theta_f}$$

The value of K (in mm^3) is given by the following equation, which assumes that the distribution of shear stress is uniform around the perimeter and across the ends of the cylinder of soil at failure.

$$\boxed{K = \pi D^2[\,(H/2) + (D/6)\,]}$$

Where;

D = overall width of the vane measured to 0.1mm (mm)

H = length of the vane measured to 0.1mm (mm)

The value of K for the vane 12.7mm wide and 12.7mm long is 4290mm^3

The value of the vane shear strength of the soil can be calculated using the equation below:

$$\boxed{\text{Vane shear strength, } \tau_v = (M/4.29) \text{ kN/m}^2}$$

For every experiment, vane shear strength is calculated in order to compare those values. Table 4.3.2.1 shows the value of vane shear strength of sample for experiment 1 to experiment 5.

EXP	Treatment	Voltage (V)	Vane Shear Strength (kPa)	
			Anode	Cathode
1	PVD with 2.5kPa Load	0	0.416	2.49
2	EVD (Copper Wire) with 2.5kPa Load	20	3.33	0.8325
3	EVD (Stainless Steel) with 2.5kPa Load	5	5.831	0.8325
4	EVD (Stainless Steel) with 2.5kPa Load	10	9.27	0.4163
5	EVD (Stainless Steel) with 2.5kPa Load	15	17.64	0.8325

Table 4.3.2.1: Shear Strength Result

4.3.3 Settlement

Test	Treatment	Voltage (V)	Settlement (mm)
1	PVD with 2.5kPa Load	0	-3.7
2	EVD (Copper Wire) with 2.5kPa Load	20	-5.8
3	EVD (Stainless Steel) with 2.5kPa Load	5	-4.63
4	EVD (Stainless Steel) with 2.5kPa Load	10	-7.01
5	EVD (Stainless Steel) with 2.5kPa Load	15	-6.05

Table 4.3.3.1: Settlement Result

4.3.4 pH

Test	Treatment	Voltage (V)	pH	
			Anode	Cathode
1	PVD with 2.5kPa Load	0	1)3.51	3)3.54
			2)3.52	4)3.52
			5)3.71	
2	EVD (Copper Wire) with 2.5kPa Load	20	1)3.26	3)3.26
			2)3.23	4)3.19
			5)3.31	
3	EVD (Stainless Steel) with 2.5kPa Load	5	1)1.93	3)10.32
			2)2.13	4)10.14
			5)3.19	
4	EVD (Stainless Steel) with 2.5kPa Load	10	1)2.70	3)10.23
			2)2.40	4)10.14
			5)3.57	
5	EVD (Stainless Steel) with 2.5kPa Load	15	1)2.27	3)10.13
			2)2.43	4)10.20
			3)3.62	
		Basic pH	5.74	

Table 4.3.4.1: pH Result

4.3.5 Current

The current readings for experiment 2, 3, 4 and 5 are shown in the Appendix B. Result shown in Table 4.3.5.1 below is the reading of the initial current value and final current value when voltage is applied.

EXP	Treatment	Voltage (V)	Current, A	
			Initial	Final
1	PVD with 2.5kPa Load	0	No Current	No Current
2	EVD (Copper Wire) with 2.5kPa Load	20	0.55	0.54

3	EVD (Stainless Steel) with 2.5kPa Load	5	0.2911	0.1067
4	EVD (Stainless Steel) with 2.5kPa Load	10	0.7281	0.1211
5	EVD (Stainless Steel) with 2.5kPa Load	15	0.7764	0.0607

Table 4.3.5.1: Current Readings

4.4 DISCUSSION

4.4.1 Moisture Content

A moisture content chart of 5 experiments conducted is plotted as Figure 4.4.1.1 below:

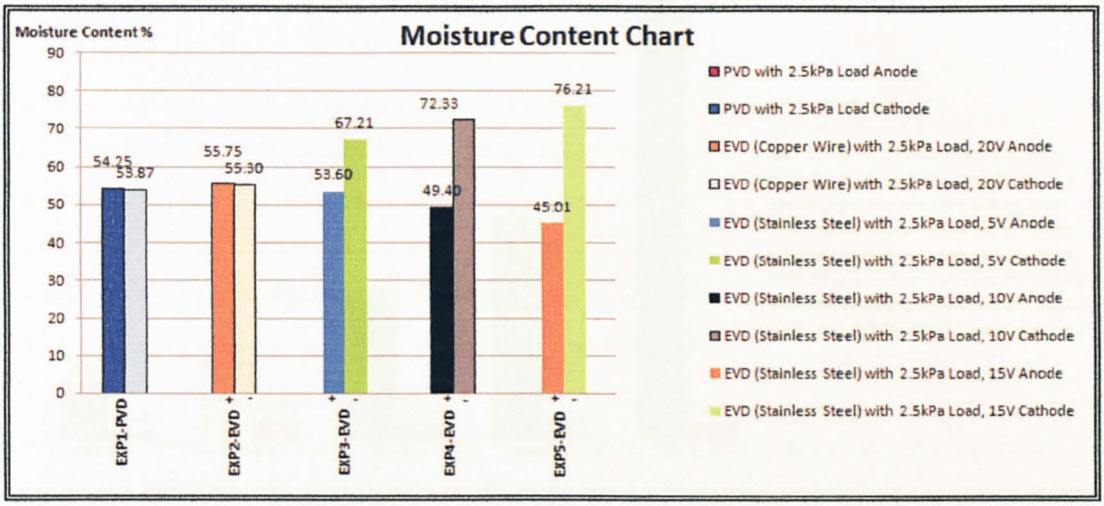

Figure 4.4.1.1: Moisture Content Chart

The water content chart is shown in Figure 4.4.1.1 for all 5 experiments conducted. From the chart, the water content after Exp 1-PVD is 54.25%, Exp 2-EVD 20V (Copper Wire incorporated inside PVD) is 55.75%, Exp 3-EVD of 5V is 53.60%, Exp 4-EVD 10V is 49.40% and Exp 5-EVD 15V is 45.01%. It can be seen that the larger increment of voltage the higher reduction of moisture content occurred at regions near anode electrodes. This is consistent with the vane shear strength increment at anode regions. From here, we can say that the moisture content of marine clay after PVD treatment is higher than EVD treatment by 1.19% to 17.03%. These water content reductions are attributed to electro osmotic consolidation that occurred throughout 7 days of experiment and also due to applied load of 2.5kPa to soil sample.

4.4.2 Shear Strength

A shear strength chart of 5 experiments conducted is plotted as Figure 4.4.2.1 below:

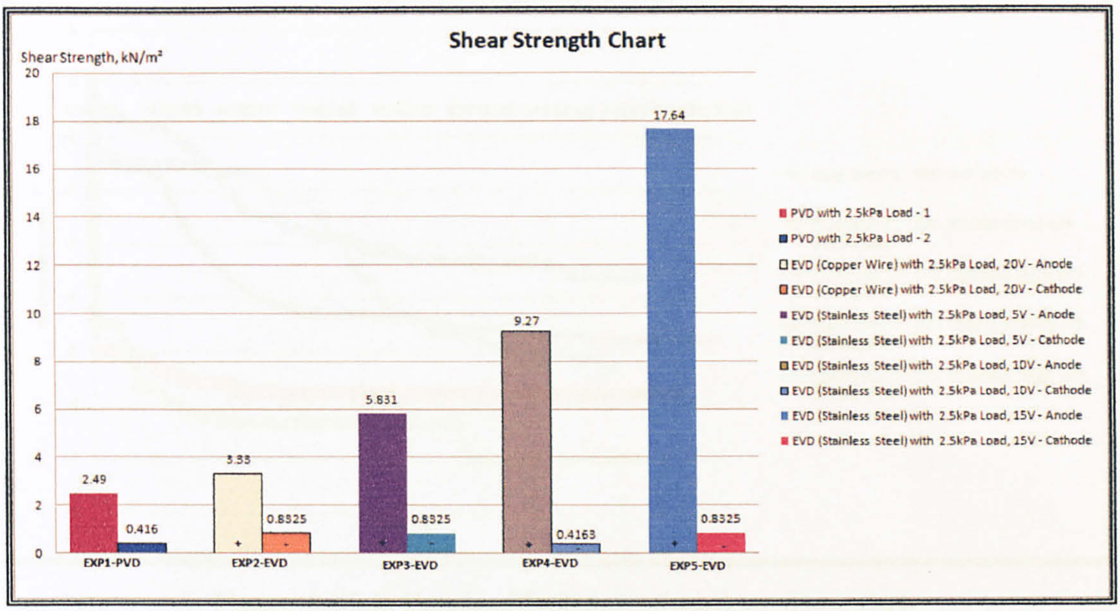

Figure 4.4.2.1: Shear Strength Chart

The Vane Shear Strength Chart is shown in Figure 4.4.2.1 for experiment 1 to 5. It can be seen that larger amount increment of shear strength occurred at soil region near anode electrode for Exp 3-EVD, Exp 4-EVD and Exp 5-EVD with applied voltage of 5V, 10V and 15V respectively compared to Exp 1-PVD. The increment of shear strength is consistent with the water content value at soil near the anode at which exhibit larger reduction in moisture content with increasing of voltage applied. As for Exp 2-EVD of 20V (Copper Wire incorporated inside PVD), this is unexpected result as the experiment shows small magnitude of increment in both current and less water content reduction compared with Exp 3-EVD of 5V, Exp 4-EVD of 10V and Exp 5-EVD of 15V. This could be due to the EVD method applied that copper wire inside PVD is not in contact with soil to allow current flow in result with no electro osmosis process occurred. From the Figure 4.4.2.1 below, it clearly showed that the marine clay shear strength after treatment of Exp 3-EVD of 5V, Exp 4-EVD of 10V and Exp 5-EVD of 15V is higher which are 5.831kPa, 9.72kPa and 17.64kPa respectively compared to shear strength of Exp 1-PVD which had 2.49kPa of shear strength.

4.4.3 Settlement

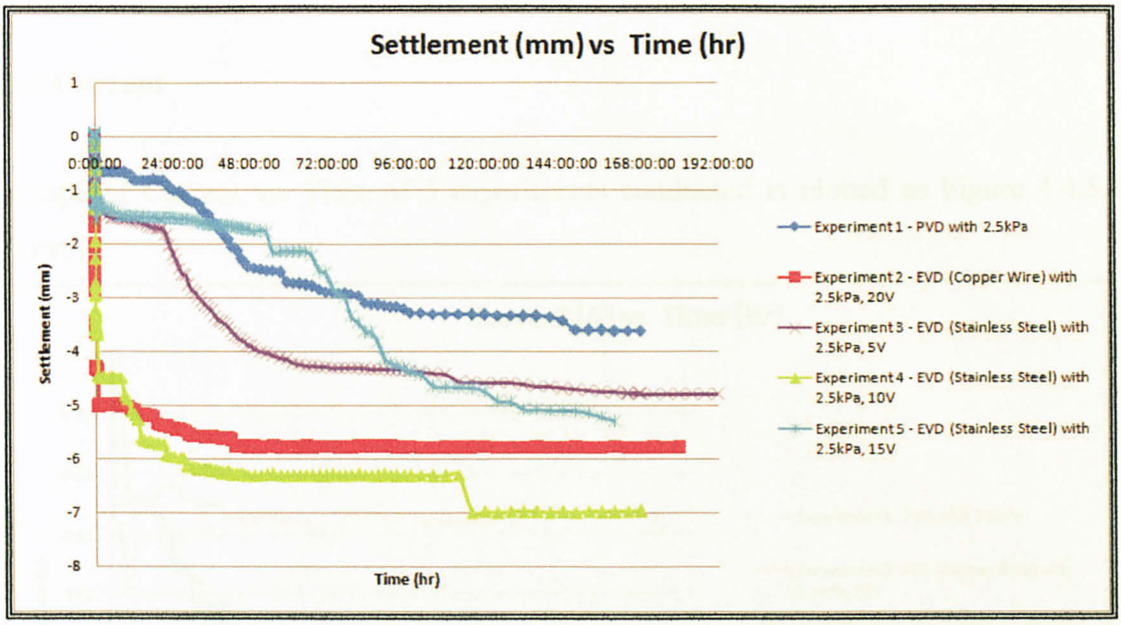

Figure 4.4.3.1: Graph of Settlement(mm) vs. Time (hr)

From Figure 4.4.3.1 above, it shows graph of settlement vs. time of 5 experiment for 7 days of treatment recorded with Settlement Gauge LVDT. Total settlements in Exp 1-PVD is 3.71mm, Exp 2-EVD (Copper wire incorporated inside PVD) is 5.8mm, Exp 3-EVD of 5V is 4.79mm, Exp 4-EVD of 10V is 7.0mm and Exp 5-EVD of 15V is 6.60mm. Therefore, the total settlement of marine clay after PVD treatment is lesser than using EVD stabilization technique by a difference of 1.08mm to 3.29mm.

4.4.4 pH

From Table 4.3.4.1, it shows changes of pH of soil near anode and cathode for 5 experiments conducted at 7 days period. The initial pH of all tests is at average of 3.52. In Exp 3-EVD of 5V, Exp 4-EVD of 10V and Exp 5-EVD of 15V, the value of pH at anode is 1.93, 2.70 and 2.27 respectively whereas, the value of pH at cathode is 10.32, 10.23 and 10.13. The changes in pH are resulted from the electrochemical reactions as shown in equation (2) and (3). The electrochemical reactions such as oxidation at anode produce acid and oxygen at the anode while generation hydrogen gas and base at cathode because of electrochemical reduction process.

4.4.5 Current

A graph of Current vs. Time of 5 experiments conducted is plotted as Figure 4.4.5.1 below:

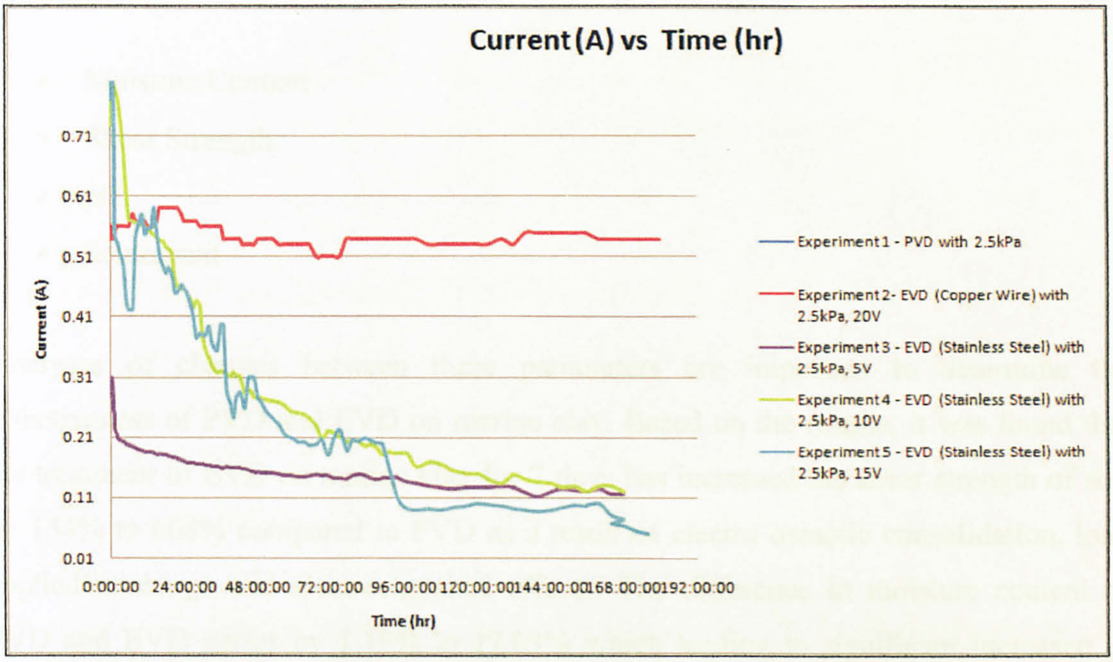

Figure 4.4.5.1: Graph of Current (A) vs. Time (hr)

The current profiles during experiments are shown in Figure 4.4.5.1 above. In Exp 1-PVD, there is no current flow as only surcharge of 2.5kPa applied to this treatment. In Exp 2-EVD (Copper wire incorporated inside PVD) the current flow is almost constant throughout 7 days of treatment. This could be due to copper wire were not in contact with the soil sample and disallowed electro osmotic process to occur. In Exp 3-EVD of 5V, Exp 4-EVD of 10V and Exp 5-EVD of 15V, the current for these 3 experiments is initially at 0.2911A, 0.7281A and 0.7764A respectively. Throughout 7 days of experiments, the current fluctuates by time and finally reach to an average of 0.1A current. This is because of the reduction of water content and due to the fact that electro osmotic treatment occurred at soil between anode and cathode.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The research and study on performance comparison between EVD and PVD on marine clay was carried out. This study focused on the laboratory tests to investigate changes on 4 important parameters after EVD and PVD treatment on marine clay which is:

- Moisture Content
- Shear Strength
- pH
- Settlement

Analyses of changes between these parameters are important to determine the effectiveness of PVD and EVD on marine clay. Based on the results, it was found that the treatment of EVD on marine clay for 7 days has increased the shear strength of soil by 134% to 608% compared to PVD as a result of electro osmotic consolidation, load applied/surcharge and electrochemical effects. The difference in moisture content of PVD and EVD varies by 1.19% to 17.03% which leading to significant increased in shear strength of marine clay after 7 days of treatment. This is clearly shows that EVD treatment on marine clay is more efficient compared with PVD treatment.

5.1 Recommendation

Several things can be done in order to improve the investigation:

- Surcharge application and removal of EVD treatment may not be needed that could result in further cost saving over conventional PVD treatment.
- Longer period of treatment to allowed more electro osmotic process and settlement to occurred

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APPENDICES

APPENDIX A: KEY MILESTONE

The progress of **Final Year Project 1** and **Final Year Project 2** are represented in separate bar charts.

Below is the milestone for Final Year Project 1. The progress of **Final Year Project 1** is shown in **Chart 1**.

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic															
	-Propose Topic															
	-Topic assigned to students															
2	Research Work															
	-Introduction															
	-Objective															
	-List of references/literature															
	-Project planning															
3	Submission of Preliminary Report															
4	Project Work															
	-Reference/Literature															
	-Practical/Laboratory Work															
5	Submission of Progress Report															
6	Project work continue															
	-Practical/Laboratory Work															
7	Submission of Interim Report Final Draft															
8	Oral Presentation															
9	Submission of Interim Report															

Chart 1: Milestone for Final Year Project 1

Below is the milestone for **Final Year Project 2.** The progress of **Final Year Project 2** is shown in **Chart 2**.

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10		11	12	13	14
1	Project Work Continue	■	■	■	■	■										
2	Submission of Progress Report 1						●									
3	Project Work Continue						■	■	■	■						
4	Submission of Progress Report 2										●					
5	Seminar (compulsory)									■	■		■			
5	Project work continue										■					
6	Poster Exhibition										●					
7	Submission of Dissertation (soft bound)												●			
8	Oral Presentation															
9	Submission of Project Dissertation (Hard Bound)														●	

Chart 2: Milestone for Final Year Project 2

● Milestone

■ Process

APPENDIX B: DATA AND CALCULATION

Moisture Content

Experiment	Electrode	Voltage	Surcharge
1 - PVD	-	-	2.5kPa
2 - EVD	Copper Wire	20V	2.5kPa
3 - EVD	Stainless Steel	5V	2.5kPa
4 - EVD	Stainless Steel	10V	2.5kPa
5 - EVD	Stainless Steel	15V	2.5kPa

Exp	Container	Weight of Container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)
1-PVD	1(1)	29.88	97.4	74.1
	1(2)	21.16	84.4	62.2
	1(3)	19.87	82.9	60.6
	2(1)	21.31	89.4	65.8
	2(2)	29.82	93.4	71.0
	2(3)	30.09	100.9	75.7
2-EVD (Copper Wire)	1(1)	18.8	76.0	55.6
	1(2)	18.8	70.0	51.8
	1(3)	23.1	86.8	64.0
	2(1)	18.9	79.3	58.1
	2(2)	23.3	76.5	57.3
	2(3)	20.7	84.3	61.3
3-EVD (Stainless Steel	1(1)	23	78.66	59.8
	1(2)	18.7	70.17	53.8
	1(3)	18.7	79.51	59.2
	2(1)	20.6	80.6	56.0
	2(2)	18.3	66.9	46.1
	2(3)	20.7	76.3	52.9

Exp	Containe r	Weight of Container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)
4-PVD (Stainless Steel)	1(1)	19.9	78.76	58.3
	1(2)	19.5	76.46	56.8
	1(3)	20.9	80.19	59.2
	2(1)	19.1	68.4	48.4
	2(2)	19.7	67.3	48.2
	2(3)	20.0	81.8	57.3
5-EVD (Stainless Steel)	1(1)	18.9	79.8	61.1
	1(2)	20.7	80.4	62.2
	1(3)	18.6	81.6	61.6
	2(1)	18.5	103.5	68.4
	2(2)	18.6	76.7	51.5
	2(3)	20.6	74.7	50.5

Calculation of moisture content

$$\text{Moisture content, } w = \frac{(m_2 - m_3)}{(m_3 - m_1)} \quad X\ 100$$

Where:

(m_1) = Mass of container
(m_2) = Mass of wet soil + container
(m_3) = Mass of dry soil + container
$(m_2 - m_3)$ = Mass of moisture
$(m_3 - m_1)$ = Mass of dry soil

Taken exp 5-EVD 1(1) as example:

$m_1 = 18.9$
$m_2 = 79.8$
$m_3 = 61.1$
$m_2 - m_3 = 18.7$
$m_3 - m_1 = 42.2$

Hence: $W = \frac{18.7}{42.2} \times 100\% = 44.31\%$ of moisture content

Vane Shear Strength

For example taking experiment 5-EVD 15V:

Deflection of spring (inner) = 58 °

Rotation of vane (outer) = 8 °

Spring rotation = 50 °

Calibration factor (inner – outer) = 42 °

Spring No. 3 was used.

The torque, M (KN/m^2) was obtained from calibration chart.

Table 1: Calibration chart

Torque		Spring No.			
Kg.cm	Nm	1	2	3	4
0.25	0.025	8	10	14	21
0.50	0.049	16	19	27	39
0.75	0.074	23	29	41	58
1.00	0.098	31	39	55	78
1.25	0.123	40	49	69	98
1.50	0.147	48	60	82	118
1.75	0.172	56	69	95	139
2.00	0.196	65	79	108	160
2.25	0.221	72	90	122	179
2.50	0.245	81	100	135	199
2.75	0.270	89	110	150	
3.00	0.295	98	120	161	
3.25	0.319	105	129	175	

By interpolation, the torque, M for 50 ° was obtained.

$$(55 - 42) / (98 - M) = (55 - 41) / (98 - 74)$$

$$M = 75.7 \text{ kN/m}^2$$

Therefore, the vane shear strength was calculated as,

$$Tv = M / k \quad (\text{KN/m}^2)$$

Where

$$K = \Pi D^2 [(H/2) + (D/6)]$$

K value is 4.29 for vane with H=12.7mm and D=12.7mm.

By assuming the vane K= 4.29 m^3 , therefore

Vane shear strength, $Tv = (75.7) / 4.29$

$= 17.64 \text{ kN/ m}^2$

Table 2: Typical Value.

Term	Undrained Shear strength (Kpa)	Visual identification
Very soft	<12.5	Exudes between fingers
Soft	12.5 – 25	Easily molded with fingers and indented considerably with thumb.
Firm	25 – 50	Can be molded with moderate pressure of fingers and indented with moderate pressure.
Stiff	50 – 100	Molded with difficulty by fingers, can be indented by strong pressure of the thumb only a small mount
Very stiff	100 - 200	Can be indented to little more then a fingerprint with strong pressure of the thumb.

Current

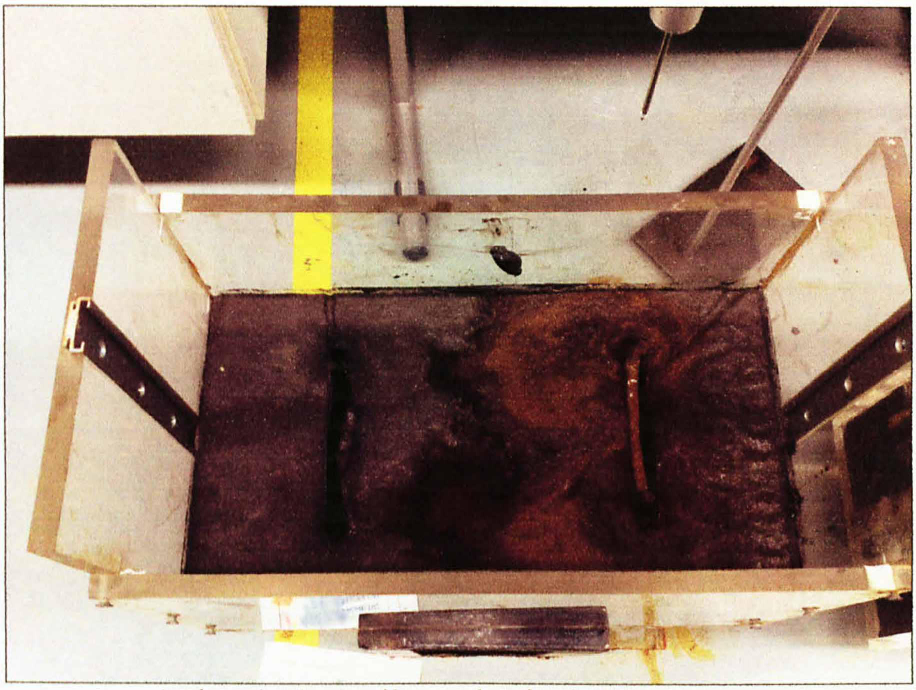
Time	EXP 2 - EVD (Copper Wire) with 2.5kPa	EXP 3 - EVD (Stainless Steel) with 2.5kPa	EXP 4 - EVD (Stainless Steel) with 2.5kPa	EXP 5 - EVD (Stainless Steel) with 2.5kPa
	Current (A), 20V	Current (A), 5V	Current (A), 10V	Current (A), 15V
0:00:05	0.55	0.2911	0.7281	0.7764
0:00:10	0.55	0.2861	0.7290	0.7769
0:00:15	0.55	0.2823	0.7295	0.7704
0:00:20	0.55	0.2816	0.7278	0.7875
0:00:25	0.55	0.2798	0.7296	0.7939
0:00:30	0.56	0.2795	0.7302	0.7883
0:00:35	0.56	0.2799	0.7314	0.8109
0:00:40	0.56	0.2803	0.7302	0.8564
0:00:45	0.56	0.2820	0.7315	0.8698
0:00:50	0.55	0.2831	0.7331	0.8739
0:00:55	0.55	0.2839	0.7352	0.8757
0:01:00	0.55	0.2842	0.7386	0.8771
0:01:05	0.55	0.2862	0.7389	0.8786
0:01:10	0.55	0.2863	0.7390	0.8786
0:01:15	0.54	0.2871	0.7395	0.879
0:01:20	0.55	0.2879	0.7400	0.8791
0:01:25	0.55	0.2888	0.7415	0.8792
0:01:30	0.55	0.2898	0.7420	0.8799
0:01:35	0.55	0.2902	0.7429	0.8802
0:01:40	0.55	0.2911	0.7435	0.8815
0:01:45	0.55	0.2924	0.7443	0.8818
0:01:50	0.55	0.2927	0.7453	0.8825
0:01:55	0.55	0.2932	0.7464	0.8825
0:02:00	0.55	0.2938	0.7469	0.8829
0:02:15	0.55	0.2962	0.7481	0.8846
0:02:30	0.55	0.2979	0.7490	0.8851
0:02:45	0.55	0.2973	0.7495	0.8866
0:03:00	0.55	0.2981	0.7478	0.8868
0:03:15	0.55	0.2991	0.7493	0.8884
0:03:30	0.55	0.2993	0.7502	0.8909
0:03:45	0.55	0.2996	0.7515	0.891
0:04:00	0.55	0.3000	0.7502	0.8912
0:04:15	0.55	0.3001	0.7515	0.8913
0:04:30	0.55	0.3009	0.7531	0.8941
0:04:45	0.55	0.3012	0.7535	0.8935
0:05:00	0.55	0.3012	0.7549	0.8923
0:05:15	0.55	0.3014	0.7557	0.8958

0:05:30	0.55	0.3017	0.7564	0.8919
0:05:45	0.55	0.3021	0.7559	0.8937
0:06:00	0.55	0.3022	0.7565	0.8959
0:06:15	0.55	0.3025	0.7577	0.8976
0:06:30	0.55	0.3028	0.7580	0.8983
0:06:45	0.55	0.3028	0.7585	0.8976
0:07:00	0.55	0.3032	0.7590	0.8973
0:07:30	0.55	0.3035	0.7593	0.9009
0:08:00	0.55	0.3039	0.7610	0.9006
0:08:30	0.55	0.3043	0.7612	0.9014
0:09:00	0.55	0.3047	0.7626	0.9033
0:09:30	0.55	0.3051	0.7623	0.9029
0:10:00	0.55	0.3052	0.7644	0.9042
0:10:30	0.55	0.3057	0.7646	0.905
0:11:00	0.55	0.3060	0.7666	0.905
0:11:30	0.55	0.3065	0.7664	0.9059
0:12:00	0.55	0.3068	0.7680	0.9043
0:12:30	0.55	0.3071	0.7681	0.9055
0:13:00	0.55	0.3075	0.7696	0.9063
0:13:30	0.55	0.3076	0.7699	0.9057
0:14:00	0.55	0.3079	0.7707	0.906
0:14:30	0.55	0.3081	0.7718	0.9062
0:15:00	0.55	0.3084	0.7782	0.9071
0:20:00	0.55	0.3014	0.7822	0.8929
0:25:00	0.55	0.3089	0.7899	0.9101
0:30:00	0.55	0.2812	0.7924	0.8976
0:35:00	0.55	0.2666	0.7884	0.8645
0:50:00	0.55	0.2558	0.7808	0.7845
0:55:00	0.55	0.2490	0.7846	0.6834
1:00:00	0.55	0.2425	0.7866	0.639
1:05:00	0.55	0.2357	0.7864	0.6053
1:10:00	0.55	0.2297	0.7880	0.5738
1:15:00	0.55	0.2241	0.7881	0.5517
1:30:00	0.55	0.2187	0.7896	0.5375
1:45:00	0.55	0.2147	0.7882	0.5314
2:00:00	0.56	0.2102	0.7751	0.5338
3:00:00	0.56	0.2059	0.7480	0.5177
4:00:00	0.56	0.2021	0.6914	0.4986
5:00:00	0.56	0.1991	0.6247	0.4421
6:00:00	0.56	0.1964	0.5743	0.4215
7:00:00	0.58	0.1942	0.5685	0.4213
8:00:00	0.57	0.1919	0.5669	0.5413
9:00:00	0.57	0.1898	0.5644	0.5611

10:00:00	0.57	0.1878	0.5631	0.5804
11:00:00	0.57	0.1864	0.5603	0.547
12:00:00	0.56	0.1856	0.5564	0.5567
13:00:00	0.56	0.1844	0.5508	0.5591
14:00:00	0.56	0.1834	0.5463	0.5908
15:00:00	0.57	0.1821	0.5419	0.5489
16:00:00	0.59	0.1823	0.5371	0.5135
17:00:00	0.59	0.1812	0.5336	0.4944
18:00:00	0.59	0.1803	0.5269	0.4839
19:00:00	0.59	0.1797	0.5243	0.4927
20:00:00	0.59	0.1777	0.5131	0.4776
21:00:00	0.59	0.1758	0.4688	0.4512
22:00:00	0.59	0.1738	0.4601	0.4531
23:00:00	0.58	0.1729	0.4572	0.4623
24:00:00	0.57	0.1711	0.4557	0.4564
25:00:00	0.57	0.1691	0.4376	0.4491
26:00:00	0.57	0.1680	0.4272	0.4294
27:00:00	0.57	0.1675	0.4369	0.4056
28:00:00	0.57	0.1662	0.4309	0.3764
29:00:00	0.56	0.1656	0.3829	0.382
30:00:00	0.56	0.1649	0.3586	0.3801
31:00:00	0.56	0.1638	0.3425	0.3795
32:00:00	0.56	0.1630	0.3310	0.394
33:00:00	0.56	0.1624	0.3231	0.3703
34:00:00	0.56	0.1623	0.3179	0.3597
35:00:00	0.56	0.1613	0.3193	0.355
36:00:00	0.56	0.1585	0.3187	0.3973
37:00:00	0.54	0.1600	0.3144	0.3967
38:00:00	0.54	0.1611	0.3116	0.29
39:00:00	0.54	0.1592	0.3180	0.2663
40:00:00	0.54	0.1594	0.3128	0.2432
41:00:00	0.54	0.1595	0.3106	0.2743
42:00:00	0.54	0.1593	0.2985	0.2844
43:00:00	0.53	0.1583	0.2827	0.2712
44:00:00	0.53	0.1574	0.2889	0.2594
45:00:00	0.53	0.1555	0.2845	0.3095
46:00:00	0.53	0.1529	0.2755	0.3111
47:00:00	0.53	0.1519	0.2748	0.3087
48:00:00	0.54	0.1523	0.2716	0.2751
49:00:00	0.54	0.1507	0.2707	0.27
51:00:00	0.54	0.1510	0.2686	0.2522
53:00:00	0.54	0.1505	0.2629	0.241
55:00:00	0.53	0.1488	0.2535	0.2305

57:00:00	0.53	0.1470	0.2506	0.2154
59:00:00	0.53	0.1460	0.2494	0.21
61:00:00	0.53	0.1451	0.2419	0.2024
63:00:00	0.53	0.1447	0.2283	0.203
65:00:00	0.53	0.1460	0.2093	0.1973
67:00:00	0.51	0.1477	0.2202	0.1989
69:00:00	0.51	0.1473	0.2174	0.2072
71:00:00	0.51	0.1475	0.2108	0.1821
73:00:00	0.51	0.1427	0.2021	0.2069
75:00:00	0.51	0.1426	0.2053	0.2228
77:00:00	0.54	0.1412	0.2021	0.1886
79:00:00	0.54	0.1464	0.1959	0.204
81:00:00	0.54	0.1485	0.1977	0.2035
83:00:00	0.54	0.1474	0.1924	0.2092
85:00:00	0.54	0.1424	0.1818	0.2051
87:00:00	0.54	0.1404	0.1857	0.2
89:00:00	0.54	0.1428	0.1838	0.1982
91:00:00	0.54	0.1428	0.1835	0.1592
93:00:00	0.54	0.1432	0.1824	0.1172
95:00:00	0.54	0.1406	0.1607	0.1007
97:00:00	0.54	0.1361	0.1685	0.0933
100:00:00	0.54	0.1333	0.1650	0.0902
104:00:00	0.53	0.1291	0.1550	0.0922
108:00:00	0.53	0.1261	0.1500	0.0903
112:00:00	0.53	0.1257	0.1499	0.0942
116:00:00	0.53	0.1268	0.1389	0.0968
120:00:00	0.53	0.1266	0.1336	0.1012
124:00:00	0.53	0.1280	0.1476	0.0991
128:00:00	0.54	0.1285	0.1399	0.0959
132:00:00	0.53	0.1263	0.1365	0.0923
136:00:00	0.55	0.1191	0.1345	0.0892
140:00:00	0.55	0.1109	0.1274	0.0883
144:00:00	0.55	0.1201	0.1291	0.0898
148:00:00	0.55	0.1247	0.1210	0.0937
152:00:00	0.55	0.1220	0.1295	0.0988
156:00:00	0.55	0.1201	0.1299	0.0977
160:00:00	0.54	0.1250	0.1211	0.0999

APPENDIX C: PHOTOGRAPHS TAKEN THROUGHOUT EXPERIMENT



A close look at soil sample after EVD treatment

5 spots of sampling